LRFD

Section 3.82

New: January 2005

Draft

3.82.1 <u>General</u>

1.1 Design Criteria

Materials

Concrete

Typically, footings shall consist of:

    Class B Concrete (Substructure) f'_c = 3.0 ksi

                                                              n = 10

Class B-1 Concrete (Substructure) may also be used in special cases (See Project Manager).

Reinforcing Steel

Minimum yield strength, f_y = 60.0 ksi

LRFD 5.4.3.2   Steel modulus of elasticity, E_s = 29000 ksi

Limit States

Service Limit State

Settlement and overall stability shall be investigated at the Service Limit State. Overall stability shall be checked where there is a sloped embankment located near the footing.

Strength Limit State

Bearing Resistance and the structural capacity of the footing shall be investigated at the Strength Limit States. Also the resultant load location shall be checked with Strength Load Combinations.
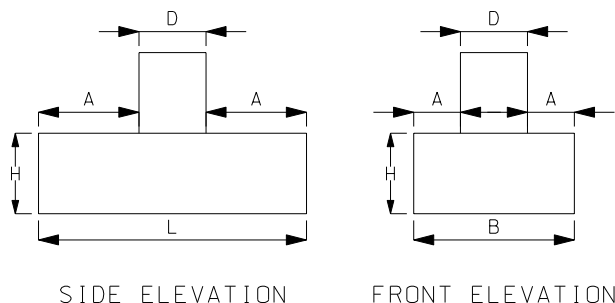
1.2 Dimensions

Figure 3.82.1.2.1 Elevations and Standard Variables for Spread Footings

Where:
D   = column diameter
A   = edge distance from column
      - Minimum of 12".
L   = footing length (3" increments)
      - Minimum of 1/6 x distance from top of beam to bottom of footing.
B   = footing width (3" increments)
      - Minimum of column diameter + 2A (3" increments).
H   = footing depth (3" increments)
      - Minimum of 30" or column diameter. For column diameters ≥ 48", use a 48" minimum footing depth.
      - Maximum of 72".

Size
The size of footing shall be determined by computing the location of the resultant force and by calculating the bearing pressure.

LRFD C10.6.1.1

Footing size should be proportioned so that stresses under the footing are as uniform as practical at the service limit state.

Long, narrow footings are to be avoided, especially on foundation material of low capacity. In general, the length to width ratio should not exceed 2.0, except on structures where the ratio of the longitudinal to transverse loads or some other consideration makes the use of such a ratio limit impractical.

Location

LRFD 10.6.1.2

If there is scour, erosion, or undermining potential, footings shall be located to bear below the maximum anticipated depth of scour, erosion, or undermining.

3.82.2 *Design*

2.1 Resultant Force Location

For eccentrically loaded footings, the location of a resultant vertical force shall be checked.

Ex. For the given loads applied to the top of a footing:
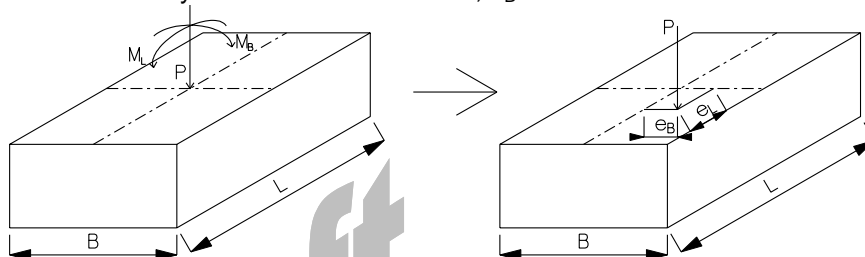Axial Load, P = 800 kips
Moment in Longitudinal Direction, M_L = 1200 k-ft
Moment in Transverse Direction, M_B = 1000 k-ft
Then,
Eccentricity in Longitudinal Direction, e_L = 1200/800 = 1.5 ft
Eccentricity in Transverse Direction, e_B = 1000/800 = 1.2 ft

Where:
e_B = eccentricity parallel to dimension *B*
e_L = eccentricity parallel to dimension *L*

Location of the Resultant Force
Table 3.71.6.1.1 represents the allowable resultant force locations for the given soil characteristics.

Table 3.82.2.1.1 Allowable Resultant Force Locations at Strength Limit State

Soil Type	Resultant Location
Soil and Shale with allowable bearing pressure < 6 tsf	Middle 1/2
Rock and Shale with allowable bearing pressure > 6 tsf	Middle 3/4

Where:

LRFD 10.6.3.3

The middle 1/2 is defined as: $\dfrac{e_L}{L}, \dfrac{e_B}{B} \leq \dfrac{1}{4}$

The middle 3/4 is defined as: $\dfrac{e_L}{L}, \dfrac{e_B}{B} \leq \dfrac{3}{8}$

2.2 Bearing Pressure

The applied bearing pressure shall be calculated with Strength Limit State Load Combinations specified in LRFD Table 3.4.1-1. The calculated bearing pressure shall be less than the allowable pressure given on the Design Layout.

For footings with eccentric loads, the area of footing used in calculating the bearing pressure shall be reduced according to the load eccentricities. The reduced area, B'xL', within the confines of the physical footing is defined as follows:
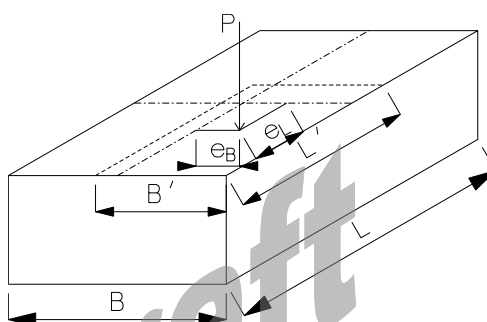

Figure 3.82.2.2.1 Bearing Pressure for Footing Loaded Eccentrically
Where:
$B' = B - 2e_B$
$L' = L - 2e_L$

LRFD 10.6.3.1.5

The design bearing pressure on the effective area shall be assumed to be uniform. The reduced effective area shall be concentric with the load.

The bearing pressure limits shall meet the following equation:
$\phi q_n \geq q_u$
Where:

LRFD 10.5.5.2.1 ϕ = 0.45

LRFD 10.6.3.2.1 q_n = nominal bearing resistance based on the uniaxial compressive rock strengths and RQD (see Design Layout)

q_u = P/(B'L')

P = maximum equivalent axial load from applicable Strength Limit State load combinations

2.3 Shear

LRFD 5.13.3.6.1

The footing is to be designed so that the shear strength of the concrete is adequate to handle the shear stress without the additional help of reinforcement. If the shear stress is too great, the footing depth should be increased.

The shear capacity of the footings in the vicinity of concentrated loads shall be governed by the more severe of the following two conditions.

One Way Shear

Critical sections shall be taken from the face of the column for square or rectangular columns or at the equivalent square face of a round column. The equivalent square column is the column which has a cross sectional area equal to the round section of the actual column and placed concentrically.
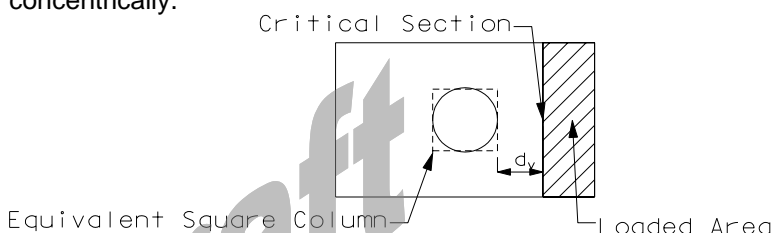

Figure 3.82.2.3.1 Critical Section For One Way Shear Design

One Way Shear Capacity,

$$V_r = \phi V_n \geq V_u$$

Where:

LRFD 5.5.4.2.1

ϕ = 0.9

LRFD 5.13.3.6.2

$$V_n = V_c = 0.0316\beta \ B \ d_v \sqrt{f'_c}$$

B = footing width

β = factor indicating ability of diagonally cracked concrete to transmit tension = 2.0

d_v = effective shear depth of concrete

V_u = v_u*(L/2 – d_v - equiv square col. width/2)*B

LRFD 10.6.5

v_u = the triangular or trapezoidal stress distribution applied to the designated loaded area of the footing from the Strength Load Combinations

LRFD 5.13.3.6.3

Two Way Shear

The critical section for checking Two Way Shear is taken from the boundary of a square area with sides equal to the equivalent square column width plus the effective shear depth as shown.
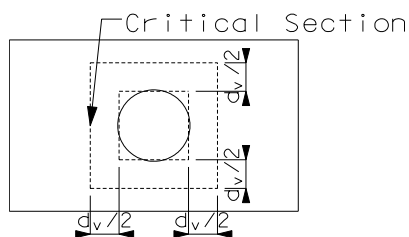
Figure 3.82.2.3.2 Critical Section For Two Way Shear Design

Two Way Shear Capacity,

$V_r = \phi V_n \geq V_u$

Where:

$$\phi V_n \quad = \phi \left(0.063 + \frac{0.126}{\beta_c} \right) b_o d_v \sqrt{f'_c} \leq 0.126 b_o d_v \sqrt{f'_c}$$

β_c = ratio of long side to short side of the rectangle through which the concentrated load or reaction force is transmitted.

b_o = perimeter of the critical section = 4*(d_v + Equivalent square column width)

d_v = effective shear depth, in.

V_u = maximum axial load on top of footing from column reactions of Strength Load Combinations.

The following table shows approximate capacities for both One Way and Two Way Shear for the given footing depth and column diameter to assist in selecting a footing length and width.

Table 3.82.2.3.1 Shear Capacities for Given Column Diameters and Footing Depths

Column Diameter FT	Footing Depth FT	One Way Shear Capacity, V_r K/FT	Two Way Shear Capacity, V_r KIPS
2.5	2.50	30.7	1074
2.5	2.75	34.3	1266
2.5	3.00	37.8	1473
2.5	3.25	41.4	1694
2.5	3.50	44.9	1928
2.75	2.75	34.3	1327
2.75	3.00	37.8	1540
2.75	3.25	41.4	1767
2.75	3.50	44.9	2008
2.75	3.75	48.5	2263
3.00	3.00	37.8	1607
3.00	3.25	41.4	1840
3.00	3.50	44.9	2087
3.00	3.75	48.5	2348
3.00	4.00	52.0	2624
3.25	3.25	41.4	1913
3.25	3.50	44.9	2166
3.25	3.75	48.5	2434
3.25	4.00	52.0	2716
3.25	4.25	55.6	3012

3.50	3.50	44.9	2246
3.50	3.75	48.5	2520
3.50	4.00	52.0	2808
3.50	4.25	55.6	3110
3.50	4.50	59.1	3426
3.75	3.75	48.5	2605
3.75	4.00	52.0	2900
3.75	4.25	55.6	3208
3.75	4.50	59.1	3531
3.75	4.75	62.7	3868
4.00	4.00	52.0	2992
4.00	4.25	55.6	3306
4.00	4.50	59.1	3635
4.00	4.75	62.7	3978
4.00	5.00	66.2	4335
4.25	4.25	55.6	3404
4.25	4.50	59.1	3740
4.25	4.75	62.7	4089
4.25	5.00	66.2	4452
4.25	5.25	69.8	4830
4.50	4.50	59.1	3844
4.50	4.75	62.7	4200
4.50	5.00	66.2	4569
4.50	5.25	69.8	4953
4.50	5.50	73.3	5351
4.75	4.75	62.7	4310
4.75	5.00	66.2	4686
4.75	5.25	69.8	5076
4.75	5.50	73.3	5481
4.75	5.75	76.8	5899
5.00	5.00	66.2	4803
5.00	5.25	69.8	5200
5.00	5.50	73.3	5610
5.00	5.75	76.8	6035
5.00	6.00	80.4	6474
5.25	5.25	69.8	5323
5.25	5.50	73.3	5740
5.25	5.75	76.8	6171
5.25	6.00	80.4	6616
5.50	5.50	73.3	5869
5.50	5.75	76.8	6306
5.50	6.00	80.4	6758
5.75	5.75	76.8	6442
5.75	6.00	80.4	6900
6.00	6.00	80.4	7042

Assumptions:

$\phi = 0.9$

$f'_c = 3$ KSI

$\beta = 2.0$

d_v = footing depth - 4"

One Way Shear Capacity = $V_r = \phi 0.0316 \beta d_v (f'_c)^{0.5}$

One Way Shear capacity is per foot width of footing.

    i.e. Total $V_r = V_r$(from table)*B

Two Way Shear Capacity = $V_r = \phi 0.126 b_o d_v (f'_c)^{0.5}$

2.4 Moment

The critical section for bending shall be taken at the face of the equivalent square column. The applied moment shall be determined from a triangular or trapezoidal stress distribution on the bottom of the footing.

The bearing pressure used to design bending reinforcement shall be calculated from Strength I, III, IV, and V Load Combinations.

Reinforcement must meet the maximum and minimum requirements as given in LRFD 5.7.3.3.1 and LRFD 5.7.3.3.2.

The minimum reinforcement allowed is #5 bars spaced at 12".

Distribution of Reinforcement

LRFD 5.13.3.5 Reinforcement in the long direction shall be distributed uniformly across the entire width of footing.

For reinforcement in the short direction, a portion of the total reinforcement shall be distributed uniformly over a band width equal to the length of the short side of footing and centered on the centerline of column or pier as shown in Figure 3.71.5.1.

The band width reinforcement required shall be calculated by the following equation:

$$A_{s\text{-}BW} = A_{s\text{-}SD}\left(\frac{2}{\beta + 1}\right)$$

Where:
$A_{s\text{-}BW}$ = area of steel in the band width, in.^{2}
$A_{s\text{-}SD}$ = total area of steel in short direction, in.^{2}
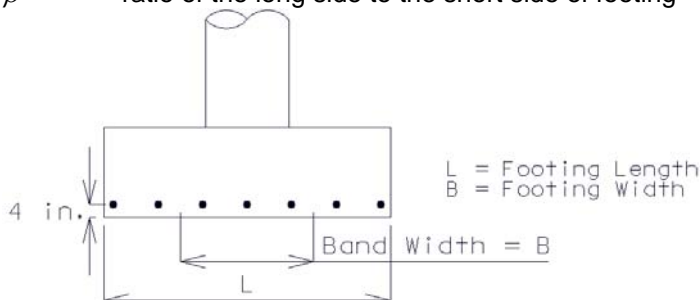β = ratio of the long side to the short side of footing

Figure 3.71.6.1.6 Distribution of Reinforcement in Spread Footing

The remainder of the reinforcement required in the short direction shall be distributed uniformly outside the center band width of footing.

3.82.3 Details

3.1 Reinforcement

Hook transverse
bar when
transverse shear
line is outside
of column.

Standard hook
(all longitudinal
reinforcement)

4" Cl.

3"
(Min.)

3"
(Min.)

By design, #5 bars
at 12" cts. (Min.)

FRONT ELEVATION

4" Cl.

6"
(Min.)

6"
(Min.)

By design, #5 bars
at 12" cts. (Min.)

SIDE ELEVATION